

CLAIMS

I CLAIM:

1. A circuit for controlling current flow through a solenoid,
5 comprising:
 - a first controllable switch electrically coupled in parallel with a first resistive element;
 - a second controllable switch electrically coupled in series with a second resistor;

10 a diode electrically coupled in series between the first controllable switch and the second controllable switch; and

15 a controller circuit operable to (i) selectively open and close the first controllable switch and the second controllable switch in response to a command signal and (ii) selectively open and close the second controllable switch based on a magnitude of current flow through the solenoid.
2. The circuit of Claim 1, wherein the controller circuit comprises:
 - a comparator circuit having at least a first input terminal coupled to a reference voltage, a second input terminal coupled to receive a voltage signal representative of a current magnitude flowing through the solenoid, and a third input terminal coupled to receive the command signal, the comparator operable to supply a switch control signal based on the signals on the first, second, and third input terminals; and
 - a driver circuit having at least a first input coupled to receive the switch control signal and operable, in response thereto, to selectively open and close the second controllable switch.

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3. The circuit of Claim 2, wherein the driver circuit further has at least a second input coupled to receive the command signal and operable, in

response thereto, to selectively open and close the first controllable switch and the second controllable switch.

4. The circuit of Claim 3, wherein the controller circuit further
5 comprises an input circuit operable to condition the command signal and supply
the conditioned command signal to the driver circuit second input and the
comparator circuit third input.

5. The circuit of Claim 2, wherein the comparator circuit comprises:
10 a comparator having a first comparator input terminal electrically coupled
to the comparator circuit first input terminal and a second comparator input
terminal electrically coupled to the comparator circuit second input terminal, and a
comparator output terminal; and
15 a logical AND circuit having a first AND circuit input coupled to the third
comparator circuit input and a second AND circuit input coupled to the
comparator output terminal and operable, in response thereto, to supply the switch
control signal.

6. The circuit of Claim 2, wherein the controller circuit further
20 comprises:
a solenoid current monitoring circuit electrically coupled to receive a
signal representative of current magnitude flowing through the solenoid and
operable, in response thereto, to supply the voltage signal representative of a
current magnitude flowing through the solenoid.

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7. The circuit of Claim 6, wherein the solenoid current monitoring
circuit comprises:
an amplifier circuit electrically coupled to receive the signal representative
of the current magnitude flowing through the solenoid and operable to provide an
30 amplified current magnitude signal; and

a timing circuit coupled to receive the amplified current magnitude signal and operable to supply the a voltage signal representative of a current magnitude flowing through the solenoid.

5 8. The circuit of Claim 1, wherein the controller supplies a first switch control signal to cause the first controllable switch to selectively open and close and a second switch control signal to cause the second controllable switch to open and close.

10 9. The circuit of Claim 8, wherein:
the first controllable switch comprises a first MOSFET having at least a gate terminal electrically coupled to receive the first switch control signal, a source terminal electrically coupled to one terminal of the first resistive element, and a drain terminal electrically coupled to another terminal of the first resistive element; and

15 the second controllable switch comprises a second MOSFET having at least a gate terminal electrically coupled to receive the second switch control signal, a source terminal electrically coupled to one terminal of the second resistor, and a drain terminal electrically coupled to a terminal of the diode.

20 10. The circuit of Claim 1, wherein:
current flows through the solenoid, the second controllable switch, and the second resistor when the first controllable switch and the second controllable switch are closed; and
25 current flows through the solenoid, the diode, and the first controllable switch when the first controllable switch is closed and the second controllable switch is open.

30 11. The circuit of Claim 10, wherein current flows through the solenoid, the diode, and the first resistive element when the first and second

controllable switches are open after being closed simultaneously for a predetermined time period.

12. The circuit of Claim 1, further comprising:

5 a solenoid coupled electrically coupled in parallel with the first controllable switch and the diode.

13. A circuit for controlling current flow through a solenoid, comprising:

10 a diode having at least a first diode terminal and a second diode terminal; a first controllable switch electrically coupled in series between the first diode terminal and a first circuit terminal, the first circuit terminal adapted for coupling the circuit to a first predetermined voltage magnitude;

15 a first resistive element having at least a first resistive element terminal and a second resistor terminal, the second resistor terminal electrically coupled to a second circuit terminal that is adapted for coupling the circuit to a second predetermined voltage magnitude;

a second controllable switch electrically coupled in series between the second diode terminal and the first resistive element terminal; and

20 a controller circuit having at least a first input coupled to receive a command signal and operable to (i) selectively open and close the first controllable switch and the second controllable switch in response to the command signal and (ii) selectively open and close the second controllable switch based on a magnitude of current flowing through the solenoid.

25 14. The circuit of Claim 13, wherein the controller circuit comprises:

a comparator circuit having at least a first input terminal coupled to a reference voltage, a second input terminal coupled to receive a voltage signal representative of a current magnitude flowing through the solenoid, and a third input terminal coupled to receive the command signal, the comparator operable to

supply a switch control signal based on the signals on the first, second, and third input terminals; and

5 a driver circuit having at least a first input coupled to receive the switch control signal and operable, in response thereto, to selectively open and close the second controllable switch.

10 15. The circuit of Claim 14, wherein the driver circuit further has at least a second input coupled to receive the command signal and operable, in response thereto, to selectively open and close the first controllable switch and the second controllable switch.

15 16. The circuit of Claim 15, wherein the controller circuit further comprises an input circuit operable to condition the command signal and supply the conditioned command signal to the driver circuit second input and the comparator circuit third input.

20 17. The circuit of Claim 14, wherein the comparator circuit comprises: a comparator having a first comparator input terminal electrically coupled to the comparator circuit first input terminal and a second comparator input terminal electrically coupled to the comparator circuit second input terminal, and a 25 comparator output terminal; and

25 a logical AND circuit having a first AND circuit input coupled to the third comparator circuit input and a second AND circuit input coupled to the comparator output terminal and operable, in response thereto, to supply the switch control signal.

18. The circuit of Claim 14, wherein the controller circuit further comprises:

30 a solenoid current monitoring circuit electrically coupled to receive a signal representative of current magnitude flowing through the solenoid and

operable, in response thereto, to supply the voltage signal representative of the current magnitude flowing through the solenoid.

5 19. The circuit of Claim 18, wherein the solenoid current monitoring circuit comprises:

an amplifier circuit electrically coupled to receive the signal representative of the current magnitude flowing through the solenoid and operable to provide an amplified current magnitude signal; and

10 a timing circuit coupled to receive the amplified current magnitude signal and operable to supply the voltage signal representative of the current magnitude flowing through the solenoid.

15 20. The circuit of Claim 14, wherein the controller supplies a first switch control signal to cause the first controllable switch to selectively open and close and a second switch control signal to cause the second controllable switch to open and close.

21. The circuit of Claim 20, wherein:
the first controllable switch comprises a first MOSFET having at least a gate terminal electrically coupled to receive the first switch control signal, a source terminal electrically coupled to one terminal of the first resistive element, and a drain terminal electrically coupled to another terminal of the first resistive element; and
the second controllable switch comprises a second MOSFET having at least a gate terminal electrically coupled to receive the second switch control signal, a source terminal electrically coupled to one terminal of the second resistor, and a drain terminal electrically coupled to a terminal of the diode.

22. The circuit of Claim 13, wherein:

the current flowing through the solenoid flows through the second controllable switch and the second resistor when the first controllable switch and the second controllable switch are closed; and

5 the current flowing through the solenoid, flows through the diode and the first controllable switch when the first controllable switch is closed and the second controllable switch is open.

10 23. The circuit of Claim 22, wherein the current flowing through the solenoid, flows through the diode and the first resistive element when the first and second controllable switches are open after being closed simultaneously for a predetermined time period.

15 24. The circuit of Claim 13, further comprising:

a solenoid coupled electrically coupled in parallel with the first controllable switch and the diode.

25. A circuit for controlling current flow through a solenoid, comprising:

20 a first MOSFET having at least a gate terminal, a source terminal, and a drain terminal;

a first resistive element having a first terminal coupled to the first MOSFET source terminal and a second terminal electrically coupled to the first MOSFET drain terminal;

25 a second MOSFET having at least a gate terminal, a source terminal, and a drain terminal;

a second resistor having a first terminal coupled to the second MOSFET source terminal;

30 a diode electrically coupled in series between the first MOSFET drain terminal and the second MOSFET source terminal; and

5 a comparator circuit having at least a first input terminal coupled to a reference voltage, a second input terminal coupled to receive a voltage signal representative of a current flowing through the solenoid, and a third input terminal coupled to receive the command signal, the comparator operable to supply a switch control signal based on the signals on the first, second, and third input terminals;

10 a solenoid current monitoring circuit electrically coupled to receive a signal representative of a magnitude of current flowing through the solenoid and operable, in response thereto, to supply the voltage signal representative of the current flowing through the solenoid; and

15 a driver circuit having at least a first input coupled to receive a command signal and a second input coupled to receive the switch control signal and operable, the driver circuit operable to selectively supply a first gate signal to the first MOSFET gate terminal in response to the command signal and to selectively supply a gate signal to the second MOSFET gate terminal in response to the switch control signal.

26. In a circuit including series connected first controllable switch and a diode that are electrically coupled in parallel with a solenoid, and a series-connected second controllable switch and first resistor that are electrically coupled in series with the solenoid, a method of controlling current flow through the solenoid, comprising:

25 closing the first and second controllable switches, whereby a current flows from a first voltage potential through the solenoid, the second controllable switch, and the first resistor;

determining when the current flow through the solenoid reaches a first predetermined current magnitude; and

opening the second controllable switch when the first predetermined current magnitude is reached, whereby the current flows through the solenoid, the diode, and the first controllable switch.

27. The method of Claim 26, further comprising:
after opening the second controllable switch, determining when the current
flow through the solenoid reaches at least a second predetermined current
magnitude, that is less than the first predetermined magnitude; and
5 closing the second controllable switch when the second predetermined
current magnitude is reached, whereby the current flows from the first voltage
potential through the solenoid, the second controllable switch, and the first
resistor.

10 28. The method of Claim 26, wherein the step of determining when the
current flow through the solenoid reaches the first predetermined current
magnitude comprises:
determining when a voltage drop across the first resistor reaches a first
15 predetermined voltage magnitude.

29. The method of Claim 27, wherein the step of determining when the
current flow through the solenoid reaches the second predetermined current
magnitude comprises:
20 determining that the second controllable switch has been opened for a
predetermined time period, such that the current flow through the solenoid has
decayed to at least the second predetermined current magnitude.

30. The method of Claim 26, further comprising:
25 opening the first and second controllable switches, whereby the current
flow through the solenoid is dissipated by a second resistor that is electrically
coupled in parallel with the first controllable switch.